Development of an Operational Data Assimilation Package using NAAPS and NAVDAS (no cost extension)

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LONG-TERM GOALS

The purpose of this research was to improve the Navy's visibility and aerosol forecasting capability through aerosol data assimilation. New and advancing satellite aerosol retrievals and datasets are allowing the scientific community to gain an unprecedented volume of observations of the global aerosol distribution. However, few efforts have been previously made to include satellite aerosol products into aerosol models through data assimilation. Such assimilation certainly benefits operational visibility and air quality forecasts.

In a previous study supported by ONR, we developed a prototype of an aerosol assimilation model (NAVDAS-AOD) for incorporating the quality assured Moderate Resolution Imaging Spectroradiometer (MODIS) level 3 aerosol product into the NRL Aerosol Analysis and Prediction System (NAAPS). The NAVDAS-AOD was developed from a 2-D variational technique based on the Naval Research Laboratory (NRL) Atmospheric Variational Data Assimilation System (NAVDAS). The goal of the work just completed was to improve the performance of NAVDAS-AOD, and develop a frame work for future multiple sensor aerosol assimilation.

OBJECTIVES

This research is destined for operational use at the Fleet Numerical Meteorological and Oceanographic Center (FNMOC) via a joint research effort led by Dr. Jeffrey Reid at the Naval Research Laboratory, and for advances in air quality, visibility and climate programs that by necessity are turning to aerosol data assimilation techniques. The specific objectives of this one-year project were:

1) The original NAVDAS-AOD system was developed with the MODIS data collection 4 optical depth data. Now obsolete, the system must be adapted and new quality assurance coefficients must be derived for the new data collection 5.

2) With the new data collection 5 data stream, we wished to perform a multi-year aerosol data assimilation test analysis to gauge model improvement. Included is not only the collection 5 over ocean, but also the NRL provided over land aerosol products generated by Edward Hyer under the Dr. J. Reid program. Lastly, we wished to test the improvement of satellite data sets of opportunity, such as the Multi-Angle Imaging Spectroradiometer (MISR).

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14. ABSTRACT
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3) Recently we gained access to global space-based lidar data. To aid in the vertical placement problem in aerosol optical depth data assimilation, we wished to develop a 3-D aerosol climatology using multi-year Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data.

WORK COMPLETED

This is a report of activities performed under a one year no-cost extension. The purpose of the extension was to complete the tasks listed under the objectives of the proposal. Most of the work done prior to this document have been detailed in the previous year's annual report (N00014-08-1-0264). In summary, we have successfully accomplished the proposed objectives. The algorithm for constructing data-assimilation quality over water MODIS aerosol product (collection 5) has been developed and transitioned to NRL. The CALIPSO aerosol climatology has been developed and incorporated in the current version of NAVDAS-AOD. The PI also collaborated with Dr. J. Reid from NRL and Dr. Edward Hyer on the over land MODIS aerosol assimilation. Results from Dr. Hyer showed that over land aerosol forecasts can also significantly benefit from the over land assimilations using the quality assured MODIS over land aerosol product.

In addition to the proposed objectives, based on the knowledge learned from this research effect, we also studied the impact of clear sky and contextual biases to satellite aerosol products that are useful for aerosol climate-related studies. We also initiated the study of multi-sensor data fusion with the combined use of MODIS, MISR and MODIS DeepBlue aerosol products through aerosol data assimilation.

RESULTS

Through a joint research effort with Dr. Zhang's ONR Young Investigator Program (YIP), new progress of this research effort specific to this year's activities includes: the development of quality assurance and emperical correction procedures for constructing a data assimilation quality MODIS over water aerosol product from the newly release collection 5 MODIS data, and finalization of the clear sky and other cloud-related contextual bias analysis. We documented our findings through peer-reviewed papers, conference presentations, and a M.S. thesis. Details of the new progress listed below are aslo included in the report assocated with N00014-08-1-0264.

Nine-years Terra and seven-years Aqua MODIS analysis for constructing data assimilation quality MODIS aerosol products: using nine years of TERRA and seven years of AQUA data, the over-water aerosol optical depth (AOD) from the Moderate Resolution Imaging Spectroradiometer (MODIS, Collection 5) aerosol products was evaluated for its potential use in aerosol data assimilation. Uncertainties in the over-water MODIS AOD were examined as functions of observing conditions, such as surface characteristics, aerosol optical properties, and cloud artifacts. Empirical corrections and quality assurance procedures were developed. After applying quality assurance and empirical correction procedures, the uncertainties in the MODIS TERRA and AQUA AOD are reduced by 20% and 12%, respectively. Nine years of TERRA and seven years of AQUA quality-assured level 3 MODIS over-water aerosol products were produced. The newly developed MODIS over-water aerosol products will be used in future aerosol data assimilation and aerosol climatology studies, and will also be useful to other researchers who are using the MODIS satellite products in their projects.

An analysis of clear sky and contextual biases (abstract from the paper, Zhang and Reid, 2009): Clear sky and other cloud-related contextual biases are critical yet unsolved mysteries for aerosol related climatological studies using satellite observations. For the first time, we simulated contextual biases over ocean using 2-years of Navy Aerosol Analysis and Prediction System (NAAPS) products that include the Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth (AOD) assimilation. We compared model-derived AOD in regions with and without observations, and found that sampling results in negligible seasonal globally averaged AOD bias (< 5%). Biases are more pronounced in regions with frequent overcast skies and high aerosol loadings, such as Southeast Asia, and mid-latitude South America. This suggests that contextual biases may develop from transport covariance and other observing biases. Lastly, we found that over remote oceans, under cloud decks, a slight increase aerosol optical depth values could exist, as compared with cloud free regions. However this effect is still small relative to cloud artifacts in the retrieval.

TRANSITIONS

Three transitions have made from this research effort.

The NAVDAS-AOD has been delivered to NRL Monterey, and is currently transitioned to FNMOC.

The algorithm for constructing a data assimilation quality MODIS collection 5 over water product has been delivered to NRL Monterey for future implementation to FNMOC.

The CALIPSO climatology is incoporated in NAVDAS-AOD, and has been delivered to NRL Monterey.

RELATED PROJECTS

This project is tightly coupled to a number of ONR 322 programs at the Marine Meteorology Division Aerosol and Radiation Section on the further development of the Navy's aerosol forecasting capabilities. This includes an integrated effort with the Earth Sciences Applications project of JS Reid on the development of NAVDAS-AOD, the model integration with the Large Scale Aerosol Modeling Development project of D. L. Westphal, and the ONR Young Investigator Program of Dr. Jianglong Zhang. Lastly, we are beginning enhancements to 3-D and 4-D variational analysis in cooperation with the NRL data assimilation section (Bill Campbell and Nancy Baker).

PUBLICATIONS

Zhang, J. and J. S. Reid, An analysis of clear sky and contextual biases using an operational over ocean MODIS aerosol product, *Geophysical Research Letters*, 36, L15824, doi:10.1029/2009GL038723, 2009 [published, refereed]..

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HONORS/AWARDS/PRIZES

Jianglong Zhang, University of North Dakota, Presidential Early Career Award for Scientists and Engineers.